AREAL SNOW COVER OBSERVATIONS IN THE CENTRAL ROCKIES, COLORADO.

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Abstract

Photographic records of areal snow cover depletion during the 1964-71 snowmelt seasons in the Fraser Experimental Forest, and in the Park Range from 1966-71, are summarized. Included are detailed estimates of snow cover extent on more than 90 hydrologic subunits which comprise the six watersheds photographed. Applications of these data in streamflow forecasting, water balance analyses, and snow cover duration are suggested.

Oxford: 587:116.12. **Keywords:** Aerial photography, photogrammetry, snow cover, streamflow forecasting.

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[1] *Central headquarters maintained at Fort Collins in cooperation with Colorado State University. Research reported here was conducted and partly financed in cooperation with the Division of Atmospheric Water Resources Management, Bureau of Reclamation, U.S. Department of the Interior.*

Contents

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Introduction

Systematic observations of areal snow cover began more than 30 years ago in the United States. Most of the observations were used to develop techniques for streamflow forecasting, however, or for specialized hydrologic studies. As a result, these records have been short-term and not generally available for much of the West. Since 1945, however, the U.S. Corps of Engineers in the North Pacific Division has collected and published snow cover data in various subdrainages of the Columbia River Basin (Thoms 1961, 1969; Thoms and Wang 1969) to supplement and provide continuity to the index "snow course" information obtained by the U.S. Soil Conservation Service. The purpose of the summaries was to make snow cover information readily available for use in hydrologic studies by other agencies.

Snow cover information is becoming increasingly important in environmental studies, and in simulating and forecasting streamflow. Therefore, this Paper summarizes the basic areal snow cover observations collected from representative watersheds in Colorado, at the Fraser Experimental Forest near Fraser, and in the Park Range near Steamboat Springs. Our analyses and application of these data are also highlighted.

Aerial photographs were used to monitor the depletion (decrease in horizontal extent) of the snow cover. Three gaged subalpine watersheds were mapped at each area. Pictures were taken from 1964-71 in the Fraser Experimental Forest and 1966-71 in the Park Range.

Location and Description of Watersheds

The areas photographed are just west of the Continental Divide (fig. 1). The watersheds near Fraser are within the Fraser Experimental Forest about 45 miles due west of Denver. Those in the Park Range are tributaries of the Yampa River, about 9 miles northeast and 9 miles southeast of Steamboat Springs. Major topographic characteristics of each watershed are summarized in table 1, detailed maps and descriptions are in the appendix.

Fraser Experimental Forest

The three watersheds photographed in the Fraser Experimental Forest are tributaries of St. Louis Creek, a north-south oriented drainage. Lodgepole pine (Pinus contorta) and spruce-fir (Picea engelmannii-Abies lasiocarpa) forests occupy the majority of the watershed areas. Deep, gravelly soils overlay Precambrian bedrock; glaciation has influenced the topography. More detailed discussions of the geology, climate, and water yields are found in Garstka et al. (1958), Haeffner (1971), Leaf (1966, 1971), Leaf and Brink (1972a), and Retzer (1962).

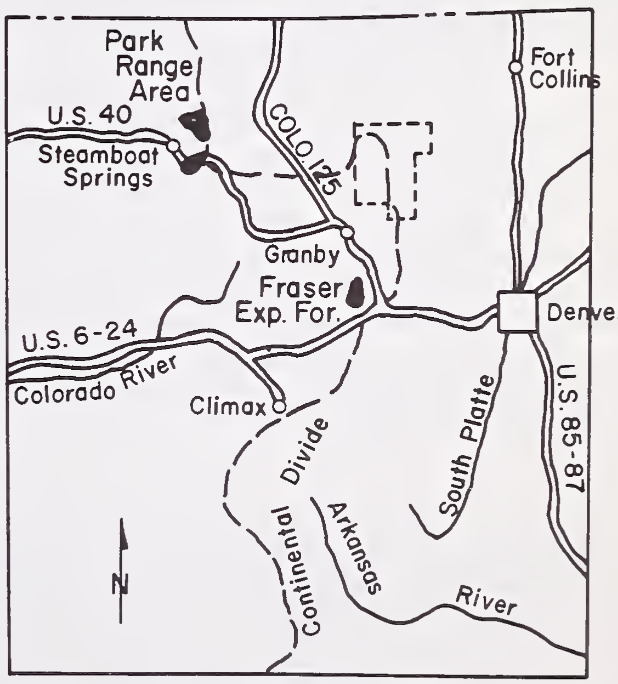

Figure 1.--Location map for the Fraser Experimental Forest and Park Range watersheds.

Table 1.--Major topographic characteristics of the study watersheds

Watershed	Area	Elevation		Approximate orientation	Area above timberline
		Range	Median		
	Acres	*Feet*	*Feet*		*Percent*
Fraser Experimental Forest:					
East St. Louis Creek	1,984	9,500-12,763	11,200	N-S	36
Deadhorse Creek	667	9,400-11,584	10,250	E-W	10
Lexen Creek	306	9,850-11,584	10,750	E-W	20
Park Range:					
South Fork Soda Creek	2,174	8,300-10,724	9,920	E-W	0
North Fork Fish Creek	1,435	9,800-10,724	10,260	NE-SW	0
West Fork Walton Creek	849	9,100- 9,728	9,280	NE-SW	0

Park Range

Three watersheds representative of the west slope of the Park Range were: South Fork Soda Creek, North Fork Fish Creek, and West Fork Walton Creek. The first two are paired watersheds northeast of Steamboat Springs, near Buffalo Pass. The headwaters of both of these watersheds consist of large alpine parks with interspersed narrow strips of spruce-fir trees generally oriented in a north-south direction. Below 10,300 feet, the forest grows in a more typical block pattern.[2] Aspen (Populus tremuloides), lodgepole pine, and extensive rock outcrops characterize the lower elevations of South Fork Soda Creek. Shallow, sparse soils overlay Precambrian bedrock; glaciation has influenced the topography.

West Fork Walton Creek is located southeast of Steamboat Springs on Rabbit Ears Pass. It supports stands of spruce-fir, lodgepole pine, and quaking aspen. Narrow strips of willows border the main stream channel and its tributaries. The soils on West Fork Walton Creek consist of deep weathered material with no indication of glacial activity. More detailed discussions of the vegetation, geology, and water yields are found in Dirmeyer,[3] Leaf and Brink (1972a), and Wilford.[2]

[2]*Wilford, B. H. 1967. Conditions and trends of forest stands within the Park Range Weather Modification study area, Routt National Forest. (Unpublished report submitted to and on file at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

[3]*Dirmeyer, R. D. 1967. Geological features affecting hydrological characteristics of Park Range experimental area. (Unpublished report submitted to and on file at Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo.)*

Observational Techniques

Aerial photography was used to get a permanent record of the areal extent of snow cover over the watersheds at about 10-day intervals during the snowmelt season. Oblique photographs were taken in 1964 at Fraser and in 1966 at the Park Range. Beginning in 1965 at Fraser and in 1967 at Park Range, vertical 9- by 9-inch photographs supplemented the obliques. Adverse flying conditions due to weather and mountainous topography affected the timing of the flights and quality of the photos. Most flights, however, provided sufficient photo overlap to achieve stereoscopic coverage at a photo scale of approximately 1:6,000.

Each watershed was subdivided into relatively homogeneous snow cover depletion units based on major physiographic and vegetation characteristics (Leaf 1969). The subdivisions and some physiographic characteristics are shown in the appendix (figs. 3-8). The snow cover in each of these units was estimated visually from the photographs with the aid of a stereoscope, weighted according to area, and summed to obtain the average watershed snow cover. Detailed estimates of the snow cover on each watershed and all subunits are presented in the appendix (tables 2-4). This information has provided input to a number of hydrologic studies of the Colorado subalpine forest ecosystem.

Analysis of Snow Cover Data

Brown and Dunford (1956) summarized the results of the first snow cover observations made at the Fraser Experimental Forest in 1950. This Paper reviews analyses of snow cover data collected in central Colorado since 1964.

Snow Cover Depletion, Runoff Relationships

After collecting 4 years of snow cover data (1964-67) at Fraser, Leaf (1967) developed a mathematical model that expressed cumulative snow cover depletion (decrease in horizontal extent) and cumulative generated runoff[4] relationships as a function of time. He showed that "characteristic" cumulative functions for these watersheds could be developed because of the consistent nature of annual snow cover depletion and runoff. Additional data, that further defined these characteristic relationships, became the basis for forecasting residual streamflow in the central Colorado Rockies (Leaf 1969). Residual flows could be predicted from accumulated streamflow amounts at the time of the snow cover determinations.

Model for Updating Streamflow Forecasts

Annual differences in overwinter snowpack accumulation and the influence of precipitation during the snowmelt season were two factors contributing to scatter about the depletion-runoff functions, and therefore, forecasting errors. To account for these differences, a model for updating streamflow forecasts during the melt season was developed (Leaf and Haeffner 1971). It is based on the snow cover depletion versus runoff relationships and a precipitation index derived from April 30 storage gage measurements adjusted for subsequent precipitation during the snowmelt runoff season. Tests during 1 year showed that successive adjustments of the precipitation indices reduced initial forecast error from an average of 20 percent to approximately 10 percent when the flow remaining was still about 80 percent of the seasonal total.

Areal Snow Cover and Disposition of Snowmelt Runoff

In a water balance study, Leaf (1971) showed that integral snow cover measurements can be effectively utilized to identify watersheds and subunits within watersheds which contribute most efficiently to streamflow. The sequence of snow cover depletion and duration of the snowmelt season on the watersheds at Fraser reflected their water-yielding capability. Heterogeneous terrain produced a longer snowmelt season, which resulted in a less efficient conversion of snowmelt into streamflow. High efficiencies were apparently the result of (1) almost complete snow cover at the time when seasonal snowmelt rates were maximum on all aspects, (2) a delayed and short snow cover depletion season, and (3) relatively low recharge and evapotranspiration losses.

[4]*Generated runoff is that quantity of snowmelt which results as streamflow (see U.S. Army 1956, Garstka et al. 1958).*

Snow Cover Duration

These studies of snow cover depletion have provided information on dates of final melt (last snow patches) on Bureau of Reclamation pilot project areas, where weather modification technology is being developed to increase water yields. Such data should be useful in analyzing the ecologic implications of weather modification. For example, ecologists have been concerned that an extended snowmelt season due to increased snow accumulation would have an adverse effect on wildlife and certain plant communities. Snow cover data obtained during wet and dry years over a wide range of meteorological conditions (1964-71 melt seasons) have given a good indication of the duration of snow cover on a long-term basis (Leaf and Brink 1972b).

Figure 2 shows duration of snow cover as a function of precipitation index (overwinter snow accumulation plus precipitation during the melt season) for three watersheds. It was found that the time required to reach a given percentage of snow cover is more dependent on precipitation index during low runoff years (index less than 100) than during high years. Thus, winter snow accumulation higher than normal apparently does not delay the disappearance of the last snow.

Photogrammetric Analysis of Snow Cover

A simple photogrammetric technique using a stereocomparator was developed to measure snow cover on selected key areas (Haeffner and Barnes 1972). By this method the percent snow cover was determined from the uncontrolled aerial photographs (photographs taken without benefit of ground control). The technique permitted: (1) a time savings in data reduction, (2) a reduced cost of aerial flights, (3) precise estimates of snow cover on an area, and (4) verification that the subjective estimates obtained using a folding stereoscope were relatively precise. In addition, the snow cover changes that were mapped on the smaller key area indexed the changes of snow cover not only on its complementary watershed, but also on nearby drainages.

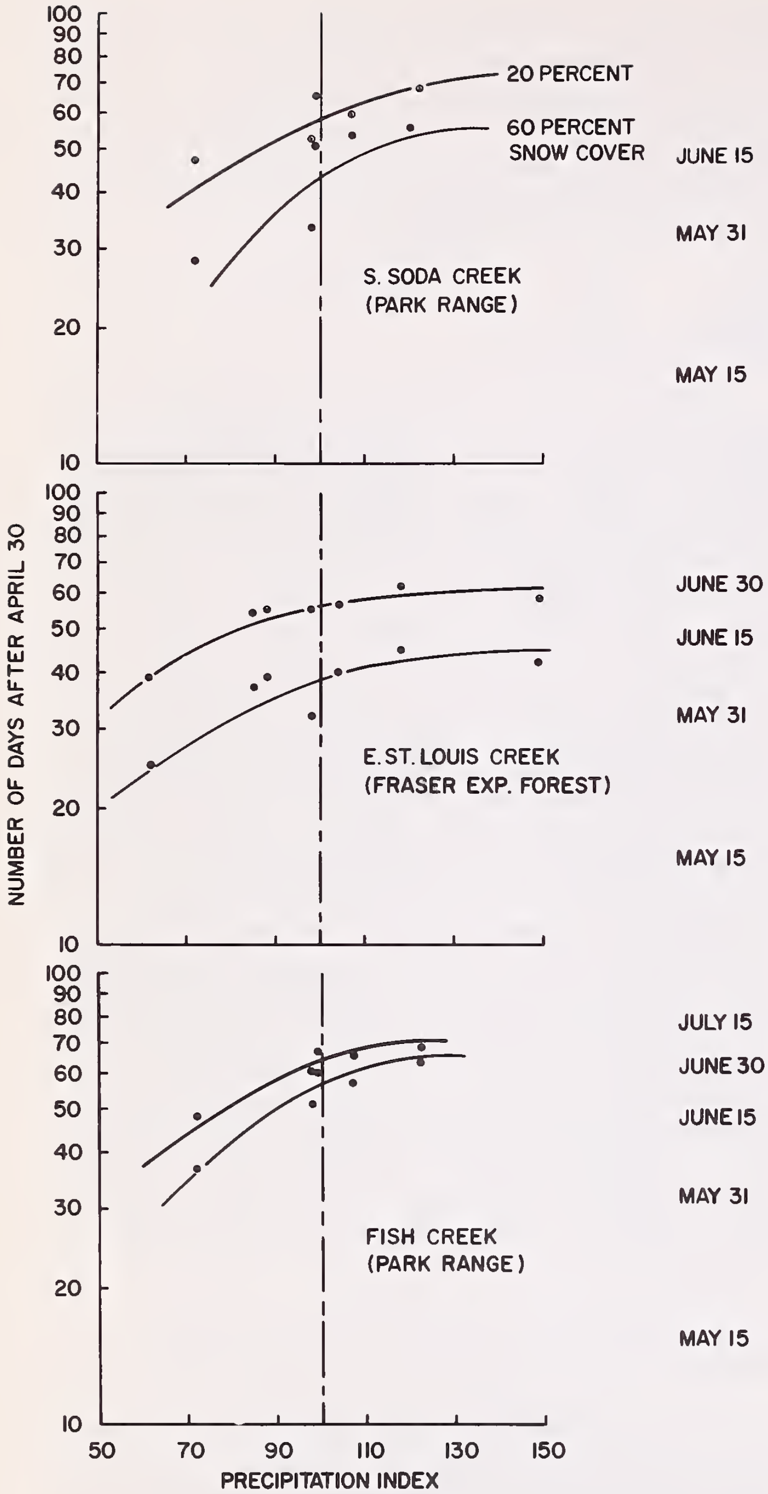

Figure 2.--Snow cover duration as a function of precipitation.

Discussion

The above summary has shown how we have used areal snow cover data for developing streamflow forecasting methods and for hydrologic analysis of subalpine watersheds.

Because these data may have other applications in ecosystems analyses, the basic snow cover estimates have been summarized (appendix, tables 2-4) in this report for use by others working in the Colorado subalpine forest zone.

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APPENDIX

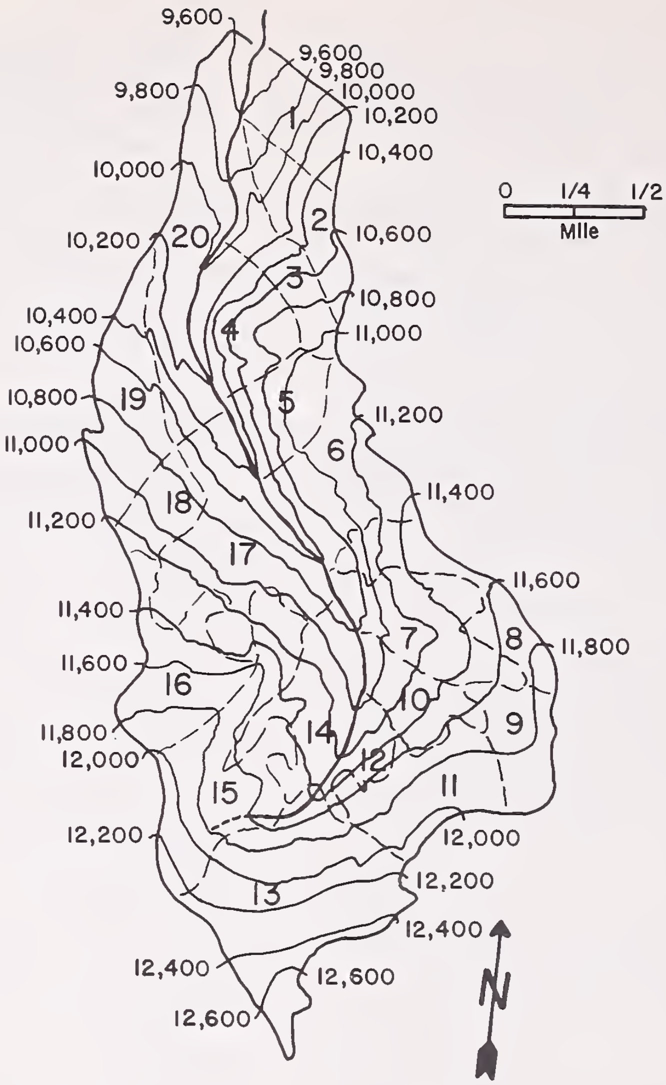

Figure 3.--East St. Louis Creek watershed (1,984 acres), Fraser Experimental Forest, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	4	9,900	WNW	100	Lodgepole pine
2	3	10,250	WNW	100	Lodgepole pine
3	3	10,250	NW	100	Lodgepole pine, spruce-fir
4	5	10,450	WNW	100	Spruce-fir
5	4	10,850	WSW	100	Spruce-fir
6	6	11,050	SW	95	Spruce-fir
7	5	11,250	W	95	Spruce-fir
8	4	11,450	W	5	Spruce-fir
9	4	11,800	NW	5	Spruce-fir
10	3	11,300	WNW	100	Spruce-fir
11	4	11,850	NW	0	--
12	2	11,250	NW	100	Spruce-fir
13	11	12,200	NNW	0	--
14	5	11,200	ENE	95	Spruce-fir
15	8	11,700	ENE	0	--
16	5	11,650	N	0	--
17	9	10,800	NNE	100	Spruce-fir
18	2	10,950	NE	100	Spruce-fir
19	5	10,700	NE	100	Lodgepole pine, spruce-fir
20	9	10,050	ENE	100	Lodgepole pine, spruce-fir

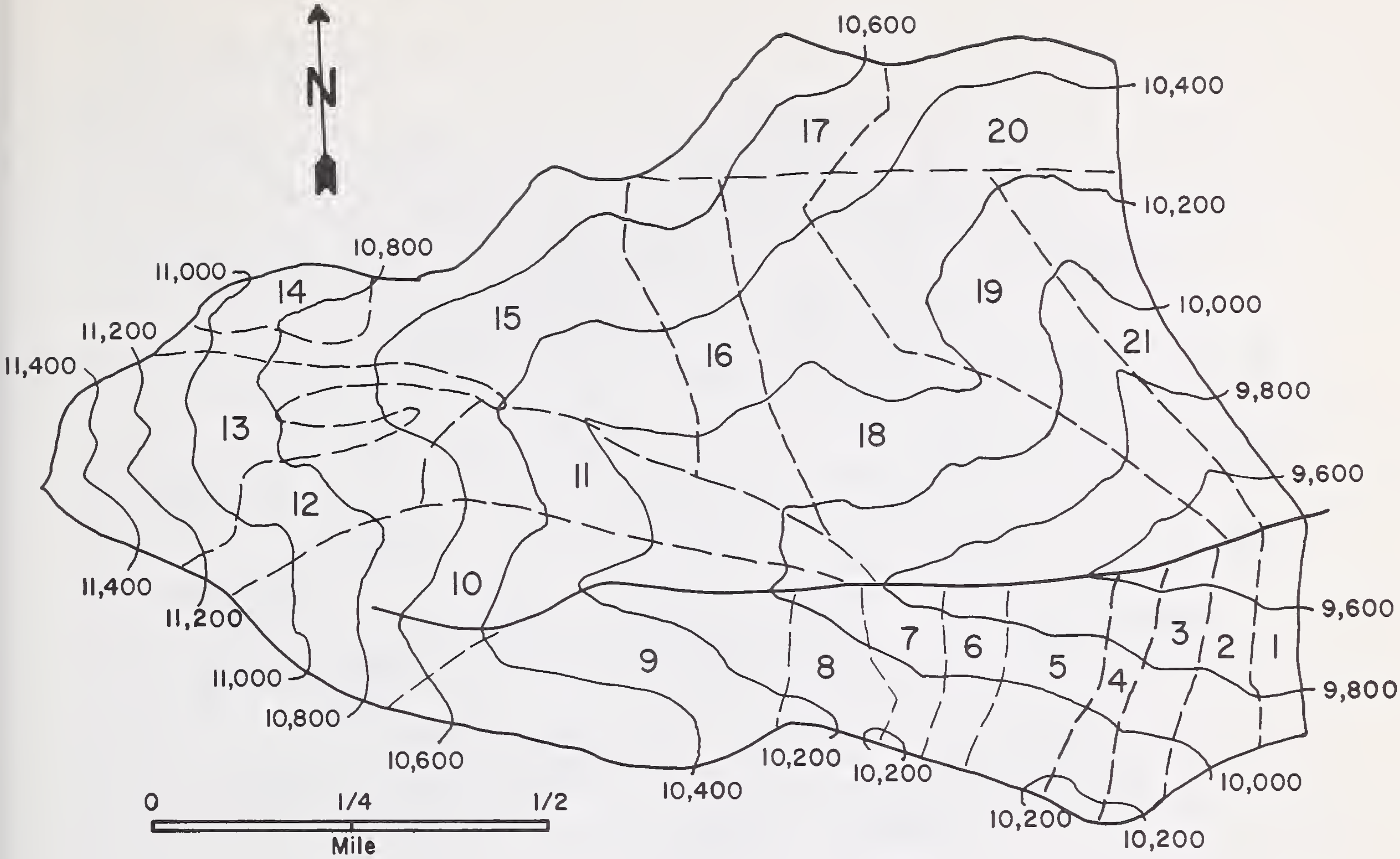

Figure 4.--Deadhorse Creek watershed (667 acres), Fraser Experimental Forest, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	1	9,650	N	100	Lodgepole pine, spruce-fir
2	2	9,700	NNE	100	Lodgepole pine
3	3	9,850	N	100	Lodgepole pine
4	2	9,900	NNE	100	Lodgepole pine
5	2	10,000	NNE	100	Lodgepole pine, spruce-fir
6	2	9,950	N	100	Lodgepole pine, spruce-fir
7	1	10,000	NNE	100	Spruce-fir
8	2	10,100	ENE	100	Spruce-fir
9	8	10,250	NNE	100	Lodgepole pine, spruce-fir
10	9	10,400	E	100	Lodgepole pine
11	5	10,200	ENE	100	Lodgepole pine, spruce-fir
12	4	10,800	NE	100	Spruce-fir
13	8	11,150	E	0	--
14	2	10,850	SSE	10	Spruce-fir
15	12	10,550	SSE	100	Lodgepole pine
16	6	10,350	SSE	100	Lodgepole pine
17	3	10,600	SE	[1]100	Lodgepole pine
18	12	10,250	SE	100	Lodgepole pine
19	8	10,050	ESE	100	Lodgepole pine
20	5	10,350	S	[1]100	Lodgepole pine
21	5	9,950	SSW	100	Lodgepole pine

[1]Cutover area.

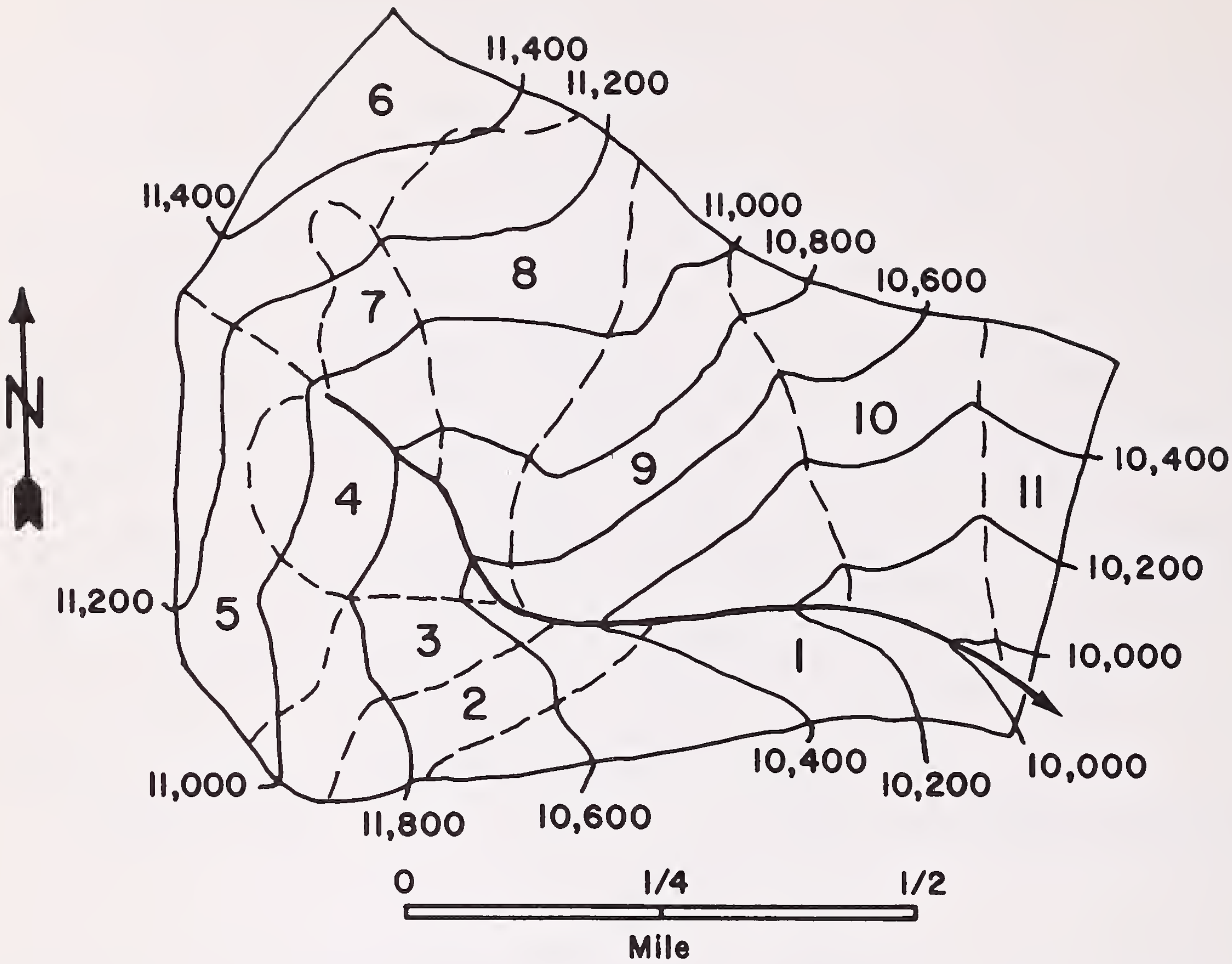

Figure 5.--Lexen Creek watershed (306 acres), Fraser Experimental Forest, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	9	10,400	NE	100	Lodgepole pine, spruce-fir
2	3	10,700	ENE	100	Spruce-fir
3	8	10,800	ENE	100	Spruce-fir
4	8	10,900	ESE	100	Spruce-fir
5	8	11,150	E	0	--
6	12	11,400	SSE	0	--
7	4	11,000	SSE	100	Spruce-fir
8	8	11,050	S	100	Lodgepole pine, spruce-fir
9	22	10,600	SE	100	Lodgepole pine
10	11	10,400	SSE	100	Lodgepole pine
11	7	10,300	SSW	100	Lodgepole pine

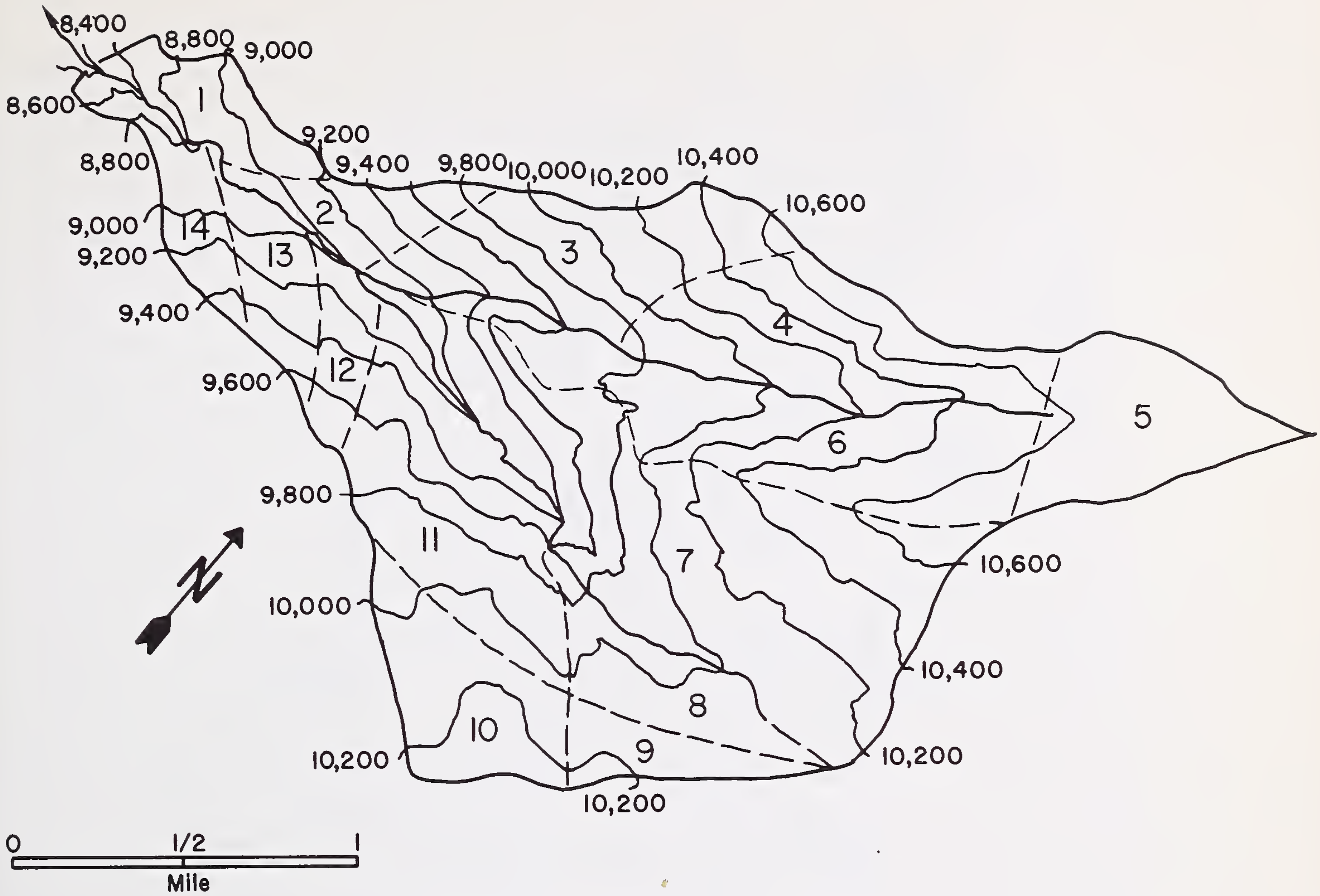

Figure 6.--South Fork Soda Creek watershed (2,174 acres), Park Range, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	4	8,900	SSW	70	Aspen
2	5	9,300	S	30	Aspen, lodgepole pine, spruce-fir
3	8	9,900	S	30	Lodgepole pine, spruce-fir
4	9	10,400	S	5	Spruce-fir
5	6	10,650	SW	[1]20	Spruce-fir
6	11	10,200	WNW	90	Spruce-fir
7	24	10,100	SSW	30	Lodgepole pine, spruce-fir
8	4	10,000	NW	30	Lodgepole pine, spruce-fir
9	3	10,150	NNW	40	Lodgepole pine, spruce-fir
10	6	10,150	NNW	40	Spruce-fir
11	9	9,700	N	30	Spruce-fir
12	4	9,400	N	10	Spruce-fir
13	4	9,200	NNW	10	Lodgepole pine
14	3	8,900	NW	10	Lodgepole pine

[1]Trees growing in strips.

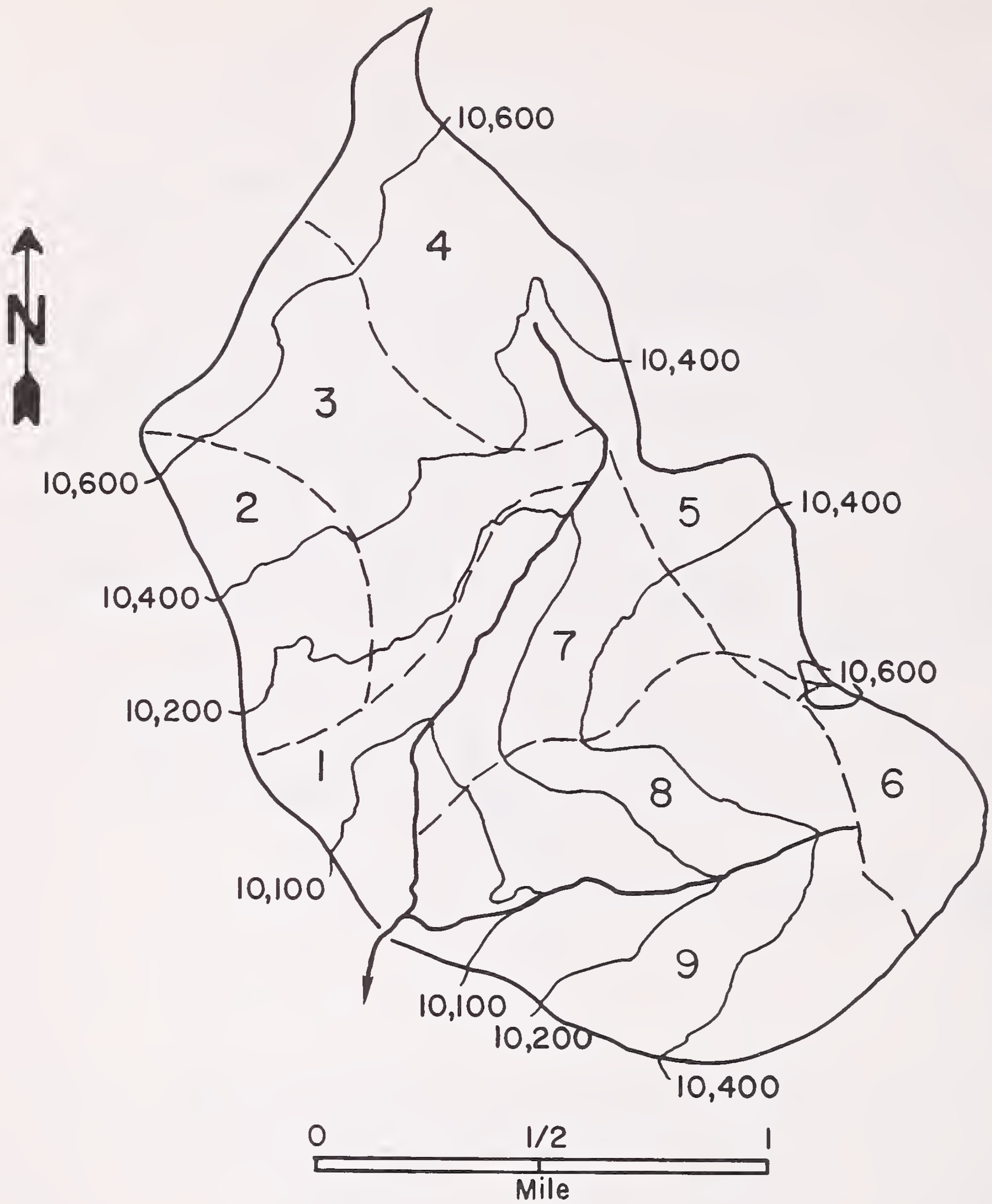

Figure 7.--North Fork Fish Creek watershed (1,435 acres), Park Range, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	14	10,000	SE	40	Spruce-fir
2	11	10,400	SE	20	Spruce-fir
3	11	10,500	SE	20	Spruce-fir
4	13	10,500	ESE	50	Spruce-fir
5	7	10,400	NNW	[1]20	Spruce-fir
6	6	10,500	W	[1]20	Spruce-fir
7	9	10,250	WNW	[1]40	Spruce-fir
8	14	10,400	SSW	[1]30	Spruce-fir
9	14	10,300	NW	60	Spruce-fir

[1]Trees growing in strips.

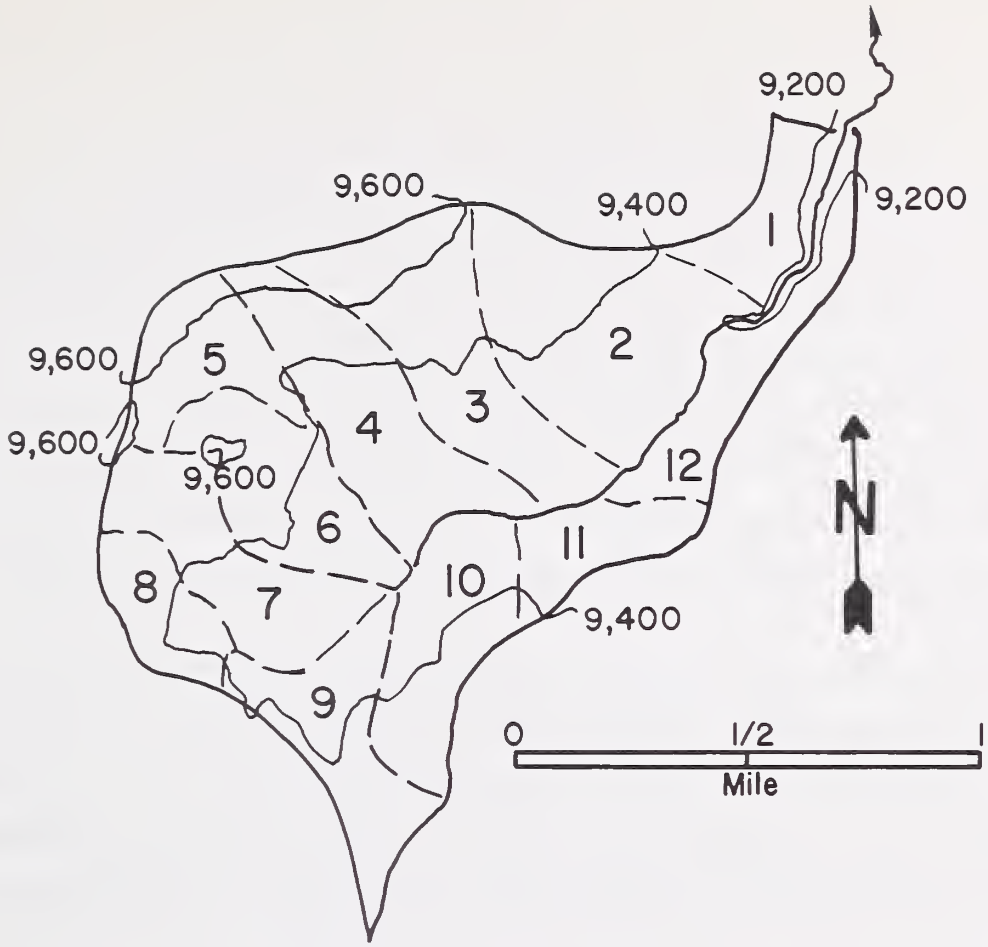

Figure 8.--West Fork Walton Creek watershed (849 acres), Park Range, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	4	9,250	ESE	95	Lodgepole pine
2	12	9,350	SE	40	Lodgepole pine
3	10	9,400	SSE	40	Lodgepole pine
4	8	9,350	S	5	Aspen
5	9	9,600	SE	0	--
6	9	9,400	SE	60	Lodgepole pine, spruce-fir
7	9	9,400	SSE	5	Lodgepole pine, spruce-fir
8	8	9,450	ESE	70	Spruce-fir
9	9	9,450	NW	90	Lodgepole pine, spruce-fir
10	9	9,400	NW	80	Lodgepole pine
11	4	9,350	NNW	60	Lodgepole pine
12	8	9,300	NW	100	Lodgepole pine

Table 2.--Estimated areal snow cover (percent, snow-covered area) by flight date, for total watershed and subunits of each watershed, Fraser Experimental Forest, 1964-71

Flight date	Total watershed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
EAST ST. LOUIS CREEK																						
1964--																						
May 7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
May 14	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
May 22	89	50	50	100	85	85	85	100	85	85	100	85	100	85	100	85	90	100	100	100	95	
June 6	54	0	0	35	20	45	50	85	50	65	100	70	100	70	100	70	70	75	75	10	0	
June 13	37	0	0	20	10	15	20	75	30	35	85	35	100	40	100	50	50	60	50	0	0	
June 25	14	0	0	0	0	0	0	20	5	15	35	20	60	25	30	30	25	20	10	0	0	
1965--																						
May 16	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
May 28	97	85	100	100	100	85	90	100	95	99	100	99	100	100	100	100	100	100	100	100	92	
June 19	50	0	0	35	25	50	35	90	40	60	100	50	100	60	100	70	80	70	45	5	0	
June 26	32	0	0	20	5	15	5	45	25	40	80	35	85	45	70	45	70	50	20	0	0	
July 4	14	0	0	2	0	0	2	15	5	15	25	20	45	20	40	30	25	20	10	0	0	
1966--																						
April 30	99	90	100	100	100	90	95	100	95	99	100	99	100	100	100	100	100	100	100	100	100	
May 18	83	40	70	90	90	80	80	100	90	90	100	90	100	90	100	90	85	95	100	75	45	
May 23	63	0	0	55	60	55	50	90	70	75	100	70	100	75	100	85	85	80	70	45	5	
May 30	48	0	0	40	30	40	35	75	50	60	95	60	90	60	90	60	75	70	35	0	0	
June 6	26	0	0	3	0	5	2	40	15	30	80	40	55	40	50	50	50	35	15	0	0	
June 24	6	0	0	0	0	0	0	0	0	0	25	10	40	15	0	15	15	0	0	0	0	
1967--																						
April 28	100	98	100	100	100	98	100	100	97	98	100	99	100	100	100	100	100	100	100	100	100	
May 16	93	85	100	100	100	75	90	100	90	90	100	90	100	90	100	90	90	100	100	100	90	
June 2	75	30	50	75	75	75	65	95	80	80	100	80	100	85	100	85	85	90	80	60	25	
June 17	40	0	0	20	0	30	15	50	40	50	95	50	90	60	80	60	80	55	35	0	0	
June 23	26	0	0	3	0	5	2	40	15	30	80	40	55	40	50	50	50	35	15	0	0	
July 2	6	0	0	0	0	0	0	0	0	0	10	10	30	15	0	30	20	0	0	0	0	
1968--																						
May 28	99	100	100	100	99	99	100	100	95	97	100	98	100	99	100	100	100	100	100	100	100	
June 3	75	30	50	75	75	75	65	95	80	80	100	80	100	85	100	85	85	90	80	60	25	
June 9	54	0	0	40	30	60	50	85	50	60	100	60	100	65	100	75	85	75	55	5	2	
June 19	42	0	0	30	5	20	25	55	35	55	95	50	90	60	85	65	80	55	20	2	0	
June 29	10	0	0	0	0	0	0	5	0	5	10	15	40	25	10	30	20	10	0	0	0	
July 5	6	0	0	0	0	0	0	0	0	0	0	10	15	20	0	25	20	0	0	0	0	
1969--																						
May 1	100	100	100	100	100	98	100	100	97	98	100	99	100	98	100	100	100	100	100	100	100	
May 15	94	75	95	100	100	80	90	100	90	98	100	98	100	98	100	98	98	100	100	100	75	
May 25	75	20	40	65	75	75	70	95	80	80	100	80	100	85	100	85	90	95	80	60	25	
June 4	50	0	0	40	30	40	40	75	40	60	90	60	95	70	90	75	80	70	35	0	0	
July 2	11	0	0	0	0	0	2	15	5	15	20	15	40	20	25	20	25	15	0	0	0	
1970--																						
June 2	75	30	50	75	75	65	65	95	80	80	100	80	100	85	100	85	85	90	90	70	25	
June 19	41	0	0	30	5	20	25	55	35	55	95	50	90	60	80	65	80	55	25	2	0	
July 1	11	0	0	0	0	0	2	15	5	15	20	15	40	20	25	20	25	15	0	0	0	
1971--																						
June 7	89	70	85	100	90	85	90	100	60	90	100	75	100	85	100	95	95	100	100	100	70	
June 12	79	55	75	90	80	60	80	95	50	80	100	65	100	75	100	90	85	95	100	90	50	
June 23	37	0	0	30	10	10	20	30	25	50	90	40	90	50	80	65	60	60	55	5	0	
DEADHORSE CREEK																						
1964--																						
May 7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
May 14	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	95	80	100	75
May 22	73	100	100	100	100	100	100	100	100	100	100	100	100	100	80	75	50	80	20	30	75	15
June 6	18	0	0	0	0	0	0	0	10	40	20	15	90	80	25	15	0	0	0	0	0	0
June 13	10	0	0	0	0	0	0	0	0	15	5	5	60	65	5	5	0	0	0	0	0	0
June 25	5	0	0	0	0	0	0	0	0	0	0	0	25	45	0	0	0	0	0	0	0	0
1965--																						
May 15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99
May 28	87	100	100	100	100	100	100	100	100	100	100	100	100	99	98	98	95	95	60	75	75	15
June 19	18	0	0	0	0	0	0	0	20	45	20	30	80	70	5	15	2	2	0	0	0	0
June 26	10	0	0	0	0	0	0	0	0	10	2	20	75	60	2	5	0	0	0	0	0	0
July 4	4	0	0	0	0	0	0	0	0	0	0	2	15	40	0	0	0	0	0	0	0	0
1966--																						
April 30	87	100	100	100	100	100	100	100	100	100	100	100	100	99	85	98	90	90	60	75	65	25
May 18	55	40	50	70	70	70	70	70	80	90	80	100	100	90	10	65	40	10	15	35	0	0
May 23	26	5	15	25	30	40	30	30	50	70	25	60	85	70	5	15	3	0	0	1	0	0
May 30	13	0	0	0	0	0	0	0	0	25	5	30	75	65	2	2	0	0	0	0	0	0
June 6	5	0	0	0	0	0	0	0	0	5	0	2	50	30	0	0	0	0	0	0	0	0
June 24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.--Estimated areal snow cover (percent, snow-covered area) by flight date, for total watershed and subunits of each watershed, Fraser Experimental Forest, 1964-71--Continued

Flight date	Total watershed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
DEADHORSE CREEK--CONTINUED																						
1967--																						
April 28	93	100	100	100	100	100	100	100	100	100	100	100	100	99	99	97	95	90	75	95	85	60
May 16	84	100	100	100	100	100	100	100	100	100	100	100	100	95	85	90	90	80	55	75	70	20
June 17	12	0	0	0	0	0	0	0	0	25	5	30	75	65	0	2	0	0	0	0	0	0
June 23	8	0	0	0	0	0	0	0	0	15	0	5	50	55	0	0	0	0	0	0	0	0
July 2	1	0	0	0	0	0	0	0	0	0	0	0	2	15	0	0	0	0	0	0	0	0
1968--																						
May 28	92	100	100	100	100	100	100	100	100	100	100	100	100	99	99	100	100	98	65	90	85	40
June 3	48	35	50	50	60	70	65	70	75	90	75	100	100	80	15	55	25	5	5	20	0	0
June 9	18	0	5	10	15	15	15	20	25	45	15	45	80	70	2	2	0	0	0	0	0	0
June 19	14	0	0	0	0	0	5	10	10	35	10	30	75	65	0	2	0	0	0	0	0	0
June 29	3	0	0	0	0	0	0	0	0	0	0	0	5	35	0	0	0	0	0	0	0	0
July 5	1	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
1969--																						
May 1	93	100	100	100	100	100	100	100	100	100	100	100	100	99	99	97	95	90	75	95	85	60
May 15	82	100	100	100	100	100	100	100	100	100	100	100	100	95	80	90	85	65	50	80	60	15
May 25	54	40	50	70	70	70	70	70	80	95	90	100	100	90	10	75	35	10	10	20	0	0
June 4	19	0	5	10	15	15	15	20	25	50	20	50	85	70	2	2	0	0	0	0	0	0
1970--																						
June 2	57	40	50	70	70	70	70	70	80	90	85	100	100	90	20	65	50	10	15	35	2	0
July 1	5	0	0	0	0	0	0	0	0	0	0	0	2	20	0	0	0	0	0	0	0	0
1971--																						
June 7	85	100	100	100	100	100	100	100	100	100	100	100	100	95	80	100	90	80	60	75	50	20
June 12	69	90	90	95	95	95	100	100	100	100	80	100	100	80	40	85	70	40	30	60	5	10
June 23	21	0	0	0	0	0	0	10	20	70	30	60	70	60	5	10	0	0	0	0	0	0
LEXEN CREEK																						
1964--																						
May 7	100	100	100	100	100	100	100	100	100	100	100	100										
May 14	100	100	100	100	100	100	100	100	100	100	100	100										
May 22	98	100	100	100	100	100	100	100	100	100	100	75										
June 6	46	30	75	100	95	98	95	50	50	0	0	0										
June 13	25	10	25	50	40	70	70	25	15	0	0	0										
June 25	15	0	0	0	5	60	55	10	0	0	0	0										
1965--																						
May 16	100	100	100	100	100	100	100	100	100	100	100	100										
May 28	100	100	100	100	100	100	100	100	100	100	100	100										
June 19	46	45	75	95	85	85	95	50	50	5	0	0										
June 26	22	20	30	50	40	65	65	20	15	0	0	0										
July 4	9	0	0	0	2	45	45	3	0	0	0	0										
1966--																						
April 30	100	100	100	100	100	100	100	100	100	100	100	100										
May 18	79	100	100	100	100	97	95	80	85	60	50	40										
May 23	55	75	95	97	90	90	90	55	60	15	5	2										
May 30	30	30	50	55	50	70	70	15	15	5	0	0										
June 6	11	2	20	10	1	45	45	2	0	0	0	0										
June 24	6	0	0	0	0	30	30	0	0	0	0	0										
1967--																						
April 28	100	100	100	100	100	100	100	100	100	100	100	100										
May 16	91	100	100	100	100	100	99	90	100	80	80	75										
June 17	30	30	40	55	65	70	70	15	15	5	0	0										
June 23	12	2	25	15	1	45	45	2	2	0	0	0										
July 2	8	0	0	0	0	40	40	0	0	0	0	0										
1968--																						
May 28	98	100	100	100	100	100	100	100	100	100	100	98										
June 3	75	95	100	100	100	95	95	85	85	50	40	30										
June 9	51	60	80	95	90	90	90	60	60	15	0	0										
June 19	29	25	45	55	45	75	75	20	25	0	0	0										
June 29	9	0	0	10	0	40	40	0	0	0	0	0										
1969--																						
May 1	100	100	100	100	100	100	100	100	100	100	100	95										
May 15	93	100	100	100	100	100	95	99	100	85	85	80										
May 25	76	100	100	100	100	95	95	75	80	55	45	35										
June 4	40	50	60	75	80	80	80	30	30	5	0	0										
1970--																						
June 2	75	95	100	100	100	95	95	85	85	50	40	30										
June 19	29	25	30	55	45	75	75	20	25	0	0	0										
June 24	22	20	20	50	40	65	65	20	15	0	0	0										
July 1	9	0	0	0	2	45	45	3	0	0	0	0										
1971--																						
June 7	84	100	100	100	100	90	90	90	100	80	50	50										
June 12	76	95	95	100	100	90	90	80	90	60	40	30										
June 23	36	50	60	80	50	70	70	20	30	10	0	0										

Table 3.--Estimated areal snow cover (percent, snow-covered area) by flight date, for total watershed and subunits of each watershed, Park Range, 1967-71

Flight date	Total watershed	1	2	3	4	5	6	7	8	9	10	11	12	13	14
						SOUTH FORK SODA CREEK									
1967--															
April 28	96	15	99	100	100	100	100	100	100	100	100	100	100	100	99
May 16	94	10	75	99	100	100	100	99	100	100	100	100	100	99	90
June 2	80	0	10	75	90	100	99	80	99	100	100	98	80	80	65
June 17	65	0	0	40	80	99	90	60	97	100	97	87	75	25	0
June 23	46	0	0	20	40	95	80	45	95	98	97	70	30	7	0
July 2	22	0	0	15	10	55	50	15	50	30	45	25	1	0	0
1968--															
May 28	97	25	98	100	100	100	100	100	100	100	100	100	100	100	95
June 3	85	2	35	85	97	100	99	85	100	100	100	99	85	85	70
June 9	80	2	5	65	90	100	100	97	100	100	100	99	85	75	50
June 19	69	0	0	50	80	99	95	85	100	100	100	90	85	50	0
July 5	18	0	0	5	5	60	50	15	45	25	35	15	0	0	0
July 13	4	0	0	0	1	35	15	0	2	2	2	1	0	0	0
1969--															
May 10	92	10	60	95	98	100	100	95	100	100	100	100	99	98	95
May 15	86	15	15	75	95	100	100	95	100	100	100	99	90	90	80
May 25	74	1	2	55	85	100	97	90	100	100	100	90	85	65	25
June 4	58	0	0	25	50	97	85	80	95	100	98	80	55	15	0
July 2	6	0	0	0	2	40	25	0	1	1	1	1	0	0	0
1970--															
June 2	90	30	50	85	99	100	99	100	100	100	100	99	90	85	80
June 21	66	0	0	40	80	99	90	85	97	100	97	90	75	35	0
July 1	39	0	0	15	30	65	70	50	80	85	80	40	5	5	0
July 15	1	0	0	1	1	10	2	1	2	3	0	0	0	0	0
1971--															
June 12	85	10	20	80	95	100	100	99	100	100	100	95	90	80	70
June 23	57	0	0	20	50	95	80	75	98	100	98	80	50	15	0
July 8	16	0	0	2	5	55	55	10	35	15	20	10	0	0	0
July 11	7	0	0	0	2	40	35	0	5	2	5	1	0	0	0
						NORTH FORK FISH CREEK									
1967--															
April 28	100	100	100	100	100	100	100	100	100	100					
May 16	100	100	100	100	100	100	100	100	100	100					
June 2	100	100	99	100	100	100	100	100	100	100					
June 17	99	99	97	99	100	100	100	99	99	99					
June 23	92	80	90	92	98	99	95	95	92	92					
July 2	50	5	20	65	70	85	77	67	20	75					
1968--															
May 28	100	100	100	100	100	100	100	100	100	100					
June 3	100	100	100	100	100	100	100	100	100	100					
June 9	100	99	100	100	100	100	100	100	100	100					
June 19	99	98	100	100	99	100	99	100	99	100					
July 5	40	7	15	45	55	80	80	60	10	55					
July 13	6	0	1	2	20	15	10	2	1	7					
1969--															
May 10	100	100	100	100	100	100	100	100	100	100					
May 15	100	100	100	100	100	100	100	100	100	100					
May 25	100	100	100	100	100	100	100	100	100	100					
June 4	96	92	85	95	100	100	99	100	95	98					
July 2	14	0	0	15	20	45	40	3	2	30					
1970--															
June 2	100	100	100	100	100	100	100	100	100	100					
June 21	99	98	99	100	99	100	98	100	99	100					
July 1	68	50	50	75	80	90	80	85	40	85					
July 15	2	0	0	0	5	5	3	1	0	5					
1971--															
June 12	100	100	100	99	100	100	100	100	100	100					
June 23	93	90	80	90	100	95	95	100	95	95					
July 8	34	5	15	45	45	70	70	35	10	50					
July 11	17	2	10	20	25	40	40	10	5	25					
						WEST FORK WALTON CREEK									
1967--															
April 28	100	100	100	100	100	100	100	100	100	100	100	100	100		
May 16	100	100	100	100	100	100	100	100	100	100	100	100	100		
June 2	78	25	85	75	70	50	80	65	80	100	100	100	90		
June 17	8	3	2	0	3	0	7	0	7	25	20	20	20		
June 23	3	0	0	0	0	0	5	0	5	7	7	5	5		
July 2	0	0	0	0	0	0	0	0	0	0	0	0	0		
1968--															
May 28	100	100	100	100	100	100	100	100	100	100	100	100	100		
June 3	100	99	100	100	99	100	97	100	100	100	100	100	100		
June 9	81	40	80	75	75	50	75	80	95	100	100	100	99		
June 19	35	15	10	10	5	15	40	25	20	80	75	75	75		
June 29	4	1	0	0	0	0	5	2	2	15	15	10	5		
July 5	0	0	0	0	0	0	0	0	0	1	1	1	0		
1969--															
May 10	100	100	100	100	100	99	99	100	100	100	100	100	100		
May 15	91	80	97	95	85	70	85	90	90	100	100	100	100		
May 25	40	20	15	15	10	25	40	25	20	80	85	90	85		
June 4	6	0	0	0	0	0	5	0	5	20	25	15	10		
July 2	0	0	0	0	0	0	0	0	0	0	0	0	0		
1970--															
June 2	100	100	100	100	100	99	99	99	100	100	100	100	100		
June 21	32	10	5	5	3	3	35	25	30	75	70	70	70		
July 1	5	0	0	0	0	0	1	2	0	15	15	15	15		
July 15	0	0	0	0	0	0	0	0	0	0	0	0	0		
1971--															
June 12	88	80	95	90	70	70	80	85	85	100	100	100	100		
June 23	27	5	2	2	2	2	30	20	40	55	65	60	65		
July 8	5	0	0	0	0	0	2	0	0	15	15	15	15		
July 11	0	0	0	0	0	0	0	0	0	0	0	0	0		

Table 4.--Summary of areal snow cover (percent, snow-covered area) by flight date, for three watersheds on Fraser Experimental Forest, 1964-71, and three watersheds in the Park Range, 1966-71

FRASER EXPERIMENTAL FOREST				PARK RANGE			
Flight date	East St. Louis	Dead-horse	Lexen	Flight date	South Fork Soda Creek	North Fork Fish Creek	West Fork Walton Creek
1964--May 7	100	100	100				
May 14	100	97	100				
May 22	89	73	98				
June 6	54	18	46				
June 13	37	10	25				
June 25	14	5	15				
1965--May 16	100	100	100				
May 28	97	87	100				
June 19	50	18	46				
June 26	32	10	22				
July 4	14	4	9				
1966--April 30	99	87	100	1966--April 30	100	100	100
May 18	83	55	79	May 18	80	100	75
May 23	63	26	55	May 23	70	100	35
May 30	48	13	30	May 29	55	95	5
June 6	26	5	11	June 6	40	60	0
June 24	6	1	6	June 23	5	5	0
1967--April 28	100	93	100	1967--April 28	96	100	100
May 16	93	84	91	May 16	94	100	100
June 2	75	--	--	June 2	80	100	78
June 17	40	12	30	June 17	65	99	8
June 23	26	8	12	June 23	46	92	3
July 2	6	1	8	July 2	22	50	0
1968--May 28	99	92	98	1968--May 28	97	100	100
June 3	75	48	75	June 3	85	100	100
June 9	54	18	51	June 9	80	100	81
June 19	42	14	29	June 19	69	99	35
June 29	10	3	9	June 29	--	--	4
July 5	6	1	--	July 5	18	40	0
				July 13	4	6	--
1969--May 1	100	93	100	1969--May 10	92	100	100
May 15	94	82	93	May 15	86	100	91
May 25	75	54	76	May 25	74	100	40
June 4	50	19	40	June 4	58	96	6
July 2	11	--	--	July 2	6	14	0
1970--June 2	75	57	75	1970--June 2	90	100	100
June 19	41	--	29	June 21	66	99	32
June 24	--	--	22	July 1	39	68	5
July 1	11	5	9	July 15	1	2	0
1971--June 7	89	85	84	1971--June 12	85	100	88
June 12	79	69	76	June 23	57	93	27
June 23	37	21	36	July 8	16	34	5
				July 11	7	17	0

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Photographic records of areal snow cover depletion during the 1964-71 snowmelt seasons in the Fraser Experimental Forest, and in the Park Range from 1966-71, are summarized. Included are detailed estimates of snow cover extent on more than 90 hydrologic subunits which comprise the six watersheds photographed. Applications of these data in streamflow forecasting, water balance analyses, and snow cover duration are suggested.

Oxford: 587:116.12. **Keywords:** Aerial photography, photogrammetry, snow cover, streamflow forecasting.

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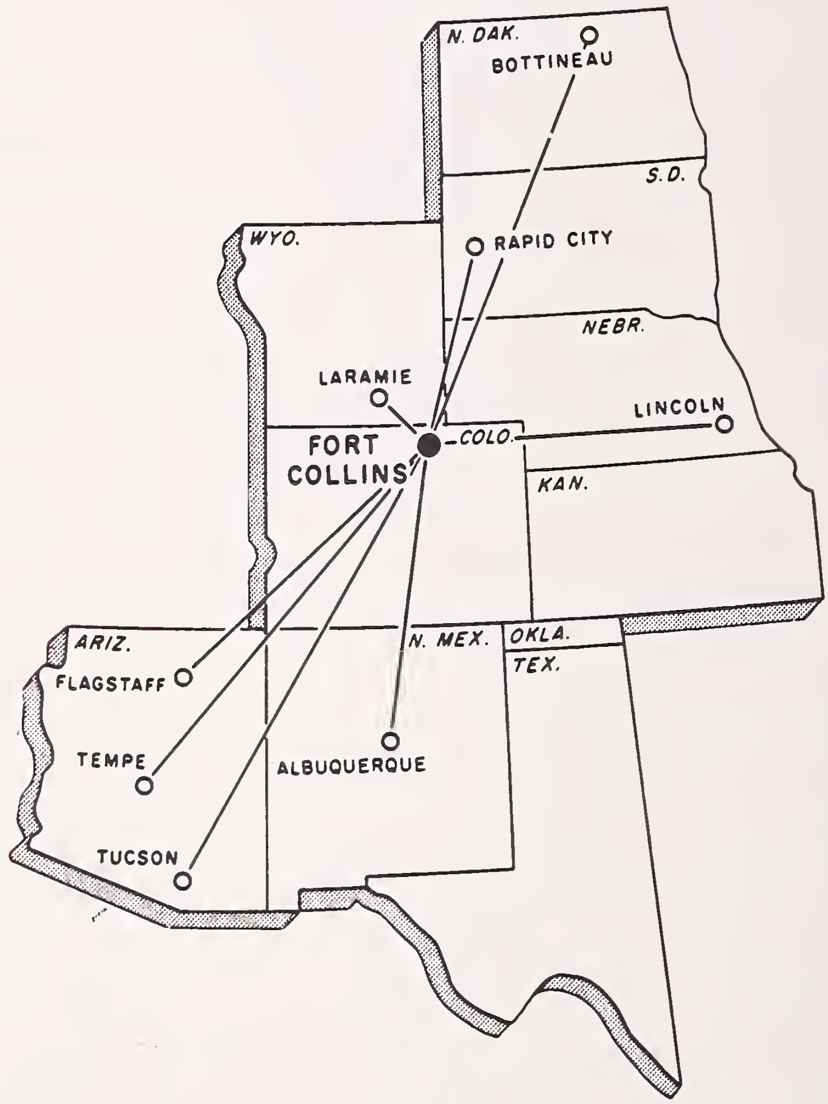
N. DAK.
BOTTINEAU
S.D.
RAPID CITY
WYO.
NEBR.
LARAMIE
LINCOLN
FORT COLLINS
COLO.
KAN.
ARIZ.
N. MEX.
OKLA.
TEX.
FLAGSTAFF
TEMPE
ALBUQUERQUE
TUCSON